

Chapter 7

Work, Energy, and Simple Machines

Redeveloped Edition | Class 9 Science | IESC Series

Original NCERT content reimagined with everyday Indian-life examples, redeveloped worked problems, and interdisciplinary insight — same rigour, re-anchored in 2026.

Opening Wonder

It's 7:10 a.m. and you're already fifteen minutes late for the school bus. You sprint up four flights of the metro station stairs, chest burning, and collapse into your seat just as the doors chime shut. Later that evening, you take the same station's escalator down — barely lifting a foot — and feel nothing at all.

Here's the puzzle: **your body moved through the same height, against the same gravity, both times.** Why did one leave you gasping and the other leave you unbothered?

Or think about the gym your older cousin has started going to, chasing the latest fitness-influencer routine. A leg press machine lets them shift 80 kg with a gentle push of the legs, while lifting even 20 kg straight off the floor with their arms feels brutal. Same weight category, wildly different effort. What is the machine actually doing to the force?

And in villages across India, at wells that still supply water for daily chores, someone lowers a bucket and hauls it back up hand over hand using a simple wheel with a rope running over it — a **pulley**. They could just as easily pull the rope sideways or upward directly. Why bother with the wheel at all?

These questions all live inside three ideas that physics ties together with surprising elegance: work, energy, and power. In everyday Hindi and English, we use these words loosely — 'that was hard work,' 'I'm out of energy,' 'she's so powerful.' Physics gives them exact, measurable meanings, and once you have those meanings, you can explain the stairs, the leg-press machine, and the well pulley with the very same handful of equations.

You already know how to track motion using forces and Newton's laws from earlier chapters. But forces that change from instant to instant, or act through twists and turns, can get mathematically messy to follow step by step. Work and energy give you a shortcut — a kind of accounting system for effort and motion that lets you skip the messy middle and jump straight to the answer. And simple machines — the pulley, the ramp, the lever — show you how humans have spent thousands of years bending that accounting system to their advantage, lifting wells' worth of water and cranes' worth of steel with far less brute force than it would otherwise take.

Think It Over

Before you read further, picture a curved slide in a park — the kind with a steep blue metal chute.

- What decides the speed of a child at the bottom of the slide — their mass, the height, or the shape of the slide?
- Would a heavier child and a lighter child, released from the same height,

reach the bottom at the same speed?

- Does it matter whether the slide is straight, curved, or spiral?

Hold onto your gut answers — you'll be able to prove them properly by the end of section 7.4.

7.1 Work Done by a Constant Force

Imagine lifting a 5 kg sack of atta (wheat flour) from the kitchen floor onto a shelf 1 m high. You apply an upward force equal to its weight, mg , and the sack moves upward by 1 m in the direction of that force. In everyday language, you'd say you 'did some work.'

Now lift three identical sacks, one after another, to the same shelf — you do **three times** as much work. Lift all three together in one go (needing three times the force, over the same 1 m) — you *still* do three times the work. Or keep a single sack but raise it to a shelf 3 m up instead of 1 m — again, three times the work. Notice the pattern: work scales directly with **both** how much force you apply *and* how far the object moves in that force's direction.

This observation becomes the precise scientific definition:

Definition

work done on an object by a constant force = force applied × displacement in the direction of the force

$$W = F \times s \quad (\text{Eq. 7.1 / 7.2})$$

The SI unit of force is the newton (N), and of displacement, the metre (m). So the SI unit of work is the **joule (J)**, where

$$1 \text{ J} = 1 \text{ N} \times 1 \text{ m} = 1 \text{ kg m s}^{-2} \times 1 \text{ m} = \mathbf{1 \text{ kg m}^2 \text{ s}^{-2}}$$

This definition works regardless of direction — vertical, horizontal, or anywhere in between, as long as F and s point the same way.

□ Everyday Connection: Your Gym's Leg Press Isn't Cheating Physics

When your cousin's leg-press machine lets them move an 80 kg stack with a light push, the *total work done* against gravity hasn't shrunk — the machine has simply changed **how** the force is applied (through a system of levers and a sliding carriage), spreading it out so each individual push feels lighter over a longer stroke. Section 7.6 will show exactly why this trick works. For now, notice: work is never 'cheated,' only *redistributed*.

7.1.1 When is work done equal to zero?

From $W = F \times s$, work is zero if **either** the force is zero, **or** there is no displacement — no matter how large the force. If you push against a locked shop shutter or shove your shoulder into a wall that doesn't budge, $s = 0$, so **you do zero work on the wall**, scientifically speaking — even though your muscles burn energy and you feel exhausted afterwards. That fatigue comes from your muscle fibres repeatedly contracting and consuming your body's internal chemical energy, not from any work being transferred to the wall.

□ **Everyday Connection: Carrying Your Schoolbag on the Metro**

When you stand on a moving metro train holding your schoolbag steady at your side, you apply an upward force on it equal to its weight, but the bag doesn't move up or down — so **you do zero work on the bag in the vertical sense**, even as the train carries you both forward. And if you instead carry the bag on your back while walking horizontally, the force you apply is upward (to support its weight) while the displacement is horizontal — force and displacement are **perpendicular**, so once again, that supporting force does zero work on the bag. (You still get tired — same reason as the wall.)

7.1.2 Positive and negative work done

When the displacement is in the **same** direction as the applied force, the work done is **positive**. When it is in the **opposite** direction, the work done is **negative**.

Push a loaded hand-cart (*thela*) forward and it moves forward — you do positive work on it. A wicketkeeper's gloves recoil backward as they absorb a fast throw — the force on the ball is opposite to the ball's motion, so the wicketkeeper does **negative** work on the ball (and by Newton's third law, the ball does positive work on the wicketkeeper's hands).

□ **Worked Example 7.1 — Redeveloped: The Wicketkeeper's Catch**

Original book version: A goalkeeper's hand moves back 15 cm while stopping a football with a force of 200 N.

Everyday Version: During a gully cricket match, a wicketkeeper's gloves move backward by 12 cm as she absorbs a fast throw from the boundary, applying a force of 250 N opposite to the ball's motion. How much work does she do on the ball while stopping it?

Working it out:

Since her hands move opposite to the ball's motion, the displacement is negative: $s = -0.12 \text{ m}$

$$W = F \times s = 250 \text{ N} \times (-0.12 \text{ m}) = -30 \text{ J}$$

The negative sign is meaningful, not a mistake — it tells us the wicketkeeper removed 30 J of kinetic energy from the ball, bringing it to rest. Work done *by* the ball on her gloves, in turn, is positive (+30 J), which is exactly why her hands sting afterward.

□ **Everyday Connection: Holding a Barbell Steady**

A weightlifter holding a loaded barbell perfectly still overhead is applying a large upward force — but since the barbell isn't moving, $s = 0$, so she does **zero work** on the barbell in this instant, by the scientific definition. Her arms, shoulders, and core are still working hard biologically (contracting muscle fibres continuously), but no mechanical work is being transferred to the barbell while it stays motionless.

7.2 The Work-Energy Theorem

When positive work is done on an object, does it gain something lasting — a *capacity* to do further work? Think of a bowler releasing a cricket ball toward the stumps: the moving ball can knock the bails off. Or a flowerpot balanced on a windowsill that, if it topples, can dent whatever it lands on. In both cases, the object has acquired the **capacity to do work on something else** — and an object with that capacity is said to possess **energy**.

Where did the ball or the pot get this capacity? The ball gained it from the work the bowler did while releasing it; the pot gained it from the work done in lifting it onto the sill. This gives us the **work-energy theorem**:

Definition

work done on an object = change in its energy (Eq. 7.3)

This holds true even for a system of several objects, and even when the force involved isn't constant — which makes it far more powerful than working through Newton's laws step by step for every changing force.

The SI unit of energy is the same as that of work — the **joule (J)**.

Meet a Scientist: James Prescott Joule (1818-1889)

The unit of both work and energy, the **joule**, is named after English physicist **James Prescott Joule**. Working largely from his family's brewery in Salford, England, Joule carried out careful experiments showing that mechanical work and heat are interchangeable forms of the same underlying quantity — energy. His measurements of the 'mechanical equivalent of heat' were central to establishing the law of conservation of energy, one of the most far-reaching principles in all of science.

□ Worked Example 7.2 — Redeveloped: A Carrom Shot

Original book version: A carrom shot where the striker hits a white coin, which then hits the black coin, pocketing it — identify who does work and how energy changes at each collision. (This example is already wonderfully Indian — carrom is one of the country's most popular board games — so we keep the scenario and add the numbers.)

Everyday Version: A player flicks the striker (mass 15 g) at 2.5 m s^{-1} toward a white coin. In the collision, the striker slows to 1.0 m s^{-1} and the white coin (mass 5 g) shoots off toward the black coin.

Working it out — energy of the striker before and after:

Before: $K = \frac{1}{2} \times 0.015 \text{ kg} \times (2.5 \text{ m s}^{-1})^2 = \frac{1}{2} \times 0.015 \times 6.25 = \mathbf{0.047 \text{ J}}$

After: $K = \frac{1}{2} \times 0.015 \text{ kg} \times (1.0 \text{ m s}^{-1})^2 = \frac{1}{2} \times 0.015 \times 1 = \mathbf{0.0075 \text{ J}}$

The striker's kinetic energy *dropped* by about 0.039 J during the collision — energy that didn't vanish, it transferred into the white coin, which now has kinetic energy it didn't have before. The striker did **positive work** on the white coin (increasing its energy) while the white coin, by Newton's third law, did **negative work** back on the striker (decreasing its energy). The same handover repeats when the white coin strikes the black coin — energy passed down a chain, collision by collision, exactly as the work-energy theorem predicts.

▮ Everyday Connection: Pedalling Uphill on a Shared Cycle

When you pedal a rented city cycle up a slope, your leg muscles supply energy converted from the food you ate — this energy appears partly as **kinetic energy** (you and the cycle speeding up), partly as **gravitational potential energy** (you climbing higher), and partly as **heat** lost to friction in the chain, tyres, and your own muscles. Not all of your effort ends up as useful motion — which is exactly why cycling uphill leaves you sweating even on a cool morning.

▮ Thread of Curiosity: Energy Doesn't Need Contact to Travel

Mechanical work — a push or a pull through a distance — is only one way energy moves from one object to another. Energy also flows as **heat**, from a hotter object to a colder one on contact (your hand warms a cold glass of water); it moves through **radiation** with no contact at all, as when the Sun's energy crosses 150 million km of empty space to reach Earth; and it travels through electric circuits and sound waves, and even in the nuclear reactions powering the Sun itself. Work is just the mechanical member of a much larger family of energy-transfer processes.

7.3 Forms of Energy

Energy is the capacity to do work, but it doesn't only show up as motion. Look around your home in the evening: **electrical energy** flows into a bulb and comes out as **light energy**; the same electrical energy flows into a water heater's coil and becomes **thermal energy**, warming your bath water; the **chemical energy** locked in your dinner powers your muscles as **mechanical energy**; and a mobile phone's ringtone converts electrical signals into **sound energy** through its tiny speaker.

Form of energy	What it means
Mechanical energy	Energy due to the motion or position of objects
Thermal energy	Energy that makes things warm or hot
Light energy	Energy that allows us to see
Sound energy	Energy carried by vibrations of air or other media
Electrical energy	Energy related to the position or motion of electric charges
Nuclear energy	Energy stored inside the nuclei of atoms
Chemical energy	Energy stored in fuels and food, in the chemical bonds between atoms

▮ Everyday Connection: Tracing Energy Through Your Evening Charge

Plug your phone into a power bank at night and you're watching an entire relay race of energy forms: chemical energy stored in the power bank's lithium-ion cells converts to electrical energy, which flows through the cable into your phone's battery, converting back into stored chemical energy there — ready to become light energy on your screen, sound energy from your speaker, and

electrical/mechanical energy in its vibration motor, the next morning. Nothing is created along the way; energy only changes costume.

□ Activity — Redeveloped: Your Morning Energy Web

Original book version: A general discussion of interdisciplinary energy conversions.

Everyday Version: Pick one appliance from your morning routine — an induction cooktop, a solar water heater, an electric kettle, or an e-bike charger. Trace its energy chain from source to final use, writing out every conversion (for example: solar radiation → thermal energy in water → useful hot water for your bath). Identify at least one point in the chain where energy is 'lost' as unwanted heat.

Of all these forms, this chapter focuses closely on **mechanical energy** — the form most directly tied to the forces and motion you have already studied.

7.4 Mechanical Energy

Mechanical energy is the energy an object possesses because of its **motion** or its **position**. Let's quantify each in turn, using the work-energy theorem as our tool.

7.4.1 Kinetic energy

The energy possessed by an object because it is moving is called **kinetic energy**. A rolling ball, a moving bicycle, an accelerating e-scooter — all possess kinetic energy. An object at rest is defined to have zero kinetic energy.

Consider an object of mass m accelerated from an initial velocity u to a final velocity v by a constant force F , over a displacement s . Using $v^2 = u^2 + 2as$, we get $s = (v^2 - u^2)/(2a)$. Since $W = F \times s = ma \times s$ (using Newton's second law, $F = ma$):

$$W = ma \times (v^2 - u^2)/(2a) = \frac{1}{2} m(v^2 - u^2) \quad (\text{Eq. 7.5})$$

By the work-energy theorem, this work equals the change in the object's energy. If the object started from rest ($u = 0$), this change *is* its final kinetic energy. So, for an object of mass m moving with velocity v :

Definition

$$K = \frac{1}{2} mv^2 \quad (\text{Eq. 7.6})$$

Kinetic energy has no direction (its unit is the joule, same as work). If positive work is done on an object, its speed and K increase; if negative work is done, both decrease; if no net work is done, K stays constant.

□ Worked Example 7.3 — Redeveloped: Doubling Your E-Scooter's Speed

Original book version: If a vehicle's velocity doubles, what happens to its kinetic energy?

Everyday Version: Your friend's rented e-scooter cruises at speed v with kinetic energy $\frac{1}{2}mv^2$. If she twists the throttle further and doubles her speed to $2v$, what happens to the kinetic energy?

$$K_{\text{new}} = \frac{1}{2} m(2v)^2 = \frac{1}{2} m \times 4v^2 = \mathbf{4 \times (\frac{1}{2} mv^2)} = 4 \times K_{\text{original}}$$

Doubling speed quadruples kinetic energy — not doubles it. This is precisely why road-safety campaigns in India stress strict speed limits near schools: a two-wheeler colliding at 40 km h⁻¹ has to dissipate **four times** the energy of one colliding at 20 km h⁻¹, in roughly the same braking distance — which is a major reason why higher-speed crashes are so much more dangerous, not just 'a bit worse.'

▢ Worked Example 7.4 — Redeveloped: The Kinetic Energy of a Fast Yorker

Original book version: An Indian cricketer bowls a 0.2 kg ball at 154.8 km h⁻¹ — find its kinetic energy at the moment of delivery.

Everyday Version (kept close to the original — it's already grounded in Indian cricket): India's fastest bowlers can clock deliveries around 150 km h⁻¹. Take the ball's mass as 0.2 kg and its speed as 154.8 km h⁻¹.

Convert speed: 154.8 km h⁻¹ = 154.8 × (1000/3600) m s⁻¹ ≈ **43 m s⁻¹**

$$K = \frac{1}{2} mv^2 = \frac{1}{2} \times 0.2 \text{ kg} \times (43 \text{ m s}^{-1})^2 = \frac{1}{2} \times 0.2 \times 1849 = \mathbf{184.9 \text{ J}}$$

That's enough energy to lift a 1.8 kg object roughly 10 m straight up — all packed into a 160 g leather ball travelling faster than most highway traffic.

▢ Everyday Connection: INS Vikrant's Arrestor Wires

The Indian Navy's aircraft carrier **INS Vikrant** uses exactly this physics to land fighter jets on a runway barely longer than a few football fields. A tail-hook on the aircraft catches a thick steel wire stretched across the deck; the wire's tension applies a huge backward force over the aircraft's short landing roll, converting its enormous kinetic energy into almost nothing within seconds — the same principle used on land-based emergency truck ramps and every aircraft carrier in the world.

▢ Ready to Go Beyond — Worked Example: Stopping a Jet on the Deck

A jet aircraft of mass 15,000 kg lands on a carrier deck. Its tail hook is caught by an arrestor wire exerting a constant backward force of 367,500 N, stopping the jet within 100 m. What was its landing speed?

$$\text{Initial KE} = \frac{1}{2} \times 15000 \text{ kg} \times v^2. \quad \text{Final KE} = 0 \text{ J.}$$

$$\text{Work done by the wire} = F \times s = 367500 \text{ N} \times (-100 \text{ m}) = -36,750,000 \text{ J}$$

(negative: force opposes displacement)

By the work-energy theorem: change in KE = work done by the wire

$$0 - \frac{1}{2} \times 15000 \times v^2 = -36,750,000 \text{ J} \implies v^2 = (36,750,000 \times 2)/15000 = 4900 \text{ m}^2 \text{ s}^{-2}$$

$v = 70 \text{ m s}^{-1} = \mathbf{252 \text{ km h}^{-1}}$ — the jet's speed just before the hook caught the wire.

7.4.2 Potential energy

Have you ever fired a **gulel** (slingshot)? Pulling back the stretched rubber band and releasing it sends the stone shooting forward — the band applies a force on the stone,

giving it kinetic energy. But where did that energy come from? It was stored in the **stretched band itself**, in the work you did earlier to deform it.

The same idea applies to a bow released by an archer, or a spring compressed and let go. Energy stored due to an object's **deformed shape or configuration** is one kind of potential energy. Energy can also be stored by changing the **relative positions** of objects in a system: separate two like poles of strong magnets and release them, and they shoot toward or away from each other, gaining kinetic energy from the stored energy of their earlier separation. The same is true of a ball raised above the Earth's surface — the Earth-ball system stores energy due to their separation, released as kinetic energy when the ball falls.

Definition

Potential energy is the energy stored by an object due to its deformation, or by a system of objects due to their relative positions.

Gravitational Potential Energy

Since the Earth is far more massive than any object near its surface, essentially all the 'stored energy' of an Earth-object system is conventionally credited to the object alone, and called its **gravitational potential energy**.

Activity 7.1 — Redeveloped: Coconuts and Sand

Original book version: Drop a heavy ball into a sand-filled container from different heights and compare the depth of the depressions it creates.

Everyday Version: Coastal Indian states are full of coconut groves. Picture a ripe coconut (mass 1.5 kg) that falls from a height of 4 m, and another that falls from 10 m, both landing on wet beach sand. Which one digs a deeper depression?

The coconut from the greater height has done more work against gravity to get there, so it carries more potential energy — and therefore more kinetic energy by the time it lands. That extra energy goes into displacing more sand, so the **10 m fall creates a visibly deeper depression** than the 4 m fall. (We'll return to this exact scenario with real numbers in the Revise, Reflect, Refine exercises.)

To find an expression for gravitational potential energy, consider an object of mass m on the ground, where we define its potential energy to be zero. To raise it gradually to a height h , we apply a force equal to mg . The work done is:

$$W = \text{force} \times \text{displacement} = mg \times h = mgh \quad (\text{Eq. 7.7})$$

By the work-energy theorem, this work becomes the object's potential energy U at height h :

Definition

$$U = mgh \quad (\text{Eq. 7.8})$$

Its unit, like all forms of energy, is the joule (J). (Note: this simple formula holds only near the Earth's surface, where g is nearly constant.)

Worked Example 7.5 — Redeveloped: A Celebration Throw

Original book version: A fielder throws a 200 g cricket ball 10 m into the air

in celebration after a catch — find its potential energy at maximum height ($g = 10 \text{ m s}^{-2}$).

Everyday Version (kept as-is — genuinely everyday already):

$$U = mgh = 0.2 \text{ kg} \times 10 \text{ m s}^{-2} \times 10 \text{ m} = \mathbf{20 \text{ J}}$$

7.4.3 Conservation of mechanical energy

The **sum of kinetic and potential energy** of an object is called its **mechanical energy**. Consider an object of mass m dropped from height h (initial velocity zero). At the top, all its mechanical energy is potential: $mgh + 0 = mgh$. As it falls for time t , using $v = gt$ and $h' = h - \frac{1}{2}gt^2$, its potential energy at that instant is $mgh - \frac{1}{2}mg^2t^2$, while its kinetic energy is $\frac{1}{2}mv^2 = \frac{1}{2}mg^2t^2$. Add them together and the t -dependent terms cancel exactly:

mechanical energy = $(mgh - \frac{1}{2}mg^2t^2) + \frac{1}{2}mg^2t^2 = \mathbf{*mgh*}$ — unchanged throughout the fall.

This is the **conservation of mechanical energy**: as an object moves under gravity alone (no friction or air resistance), its mechanical energy stays constant — potential energy converts into kinetic energy (or back again) without any net loss.

□ Activity 7.2 — Redeveloped: The Park Jhula (Swing)

Original book version: Set up a simple pendulum, mark the height of its resting position on a wall behind it, and release the bob from one side to watch it rise to nearly the same height on the other side.

Everyday Version: Next time you're at a park with a **jhula** (swing), watch closely as a friend swings on it. Mark (mentally, or with a phone video) the exact height of the seat when it's released from one side.

At the highest point on either side, the swing is momentarily still — all potential energy, zero kinetic energy. At the lowest point of the arc, it moves fastest — all kinetic energy, and (by our reference) zero potential energy. Because mechanical energy is conserved, the swing should rise to **almost exactly the same height** on the far side as it started — 'almost,' because friction at the swing's pivot and air resistance quietly drain away a little energy each pass, which is also why a jhula eventually slows down and stops if nobody keeps pushing it.

□ Worked Example 7.6 — Redeveloped: The Water-Park Slide

Original book version: What is the speed of a child at the bottom of a slide of height h ? (This is exactly the puzzle posed in this chapter's opening Think It Over box.)

Everyday Version: At a water park like Wonderla, a child slides down a chute of height h , starting from rest. Neglecting friction, what is her speed at the bottom?

Potential energy at top = mgh . Kinetic energy at bottom = $\frac{1}{2}mv^2$.

By conservation of mechanical energy: $\frac{1}{2}mv^2 = mgh \Rightarrow v = \sqrt{2gh}$

The mass of the child cancels out completely — and so does the exact shape of the slide (straight, curved, or spiral), as long as friction is negligible! A heavier child and a lighter child released from the same height reach the bottom with the **same speed**. Only the height matters.

▣ Worked Example 7.7 — Redeveloped: A Runaway-Truck Ramp in the Hills

Original book version: A truck's brakes fail on a highway; it is steered onto a sand/gravel escape ramp inclined at 30° , which brings it to rest — find the minimum ramp length.

Everyday Version (kept close to the original — these ramps genuinely exist on Himachal Pradesh and Uttarakhand hill highways): A 10,000 kg truck moving at 72 km h^{-1} ($= 20 \text{ m s}^{-1}$) has its brakes fail on a mountain descent. The driver steers onto a 30° escape ramp, where sand exerts a constant 50,000 N force opposing the truck's motion until it stops. (Hint: on a 30° incline, the truck rises 1 m vertically for every 2 m travelled along the ramp.)

Initial KE $= \frac{1}{2} \times 10000 \text{ kg} \times (20 \text{ m s}^{-1})^2 = \mathbf{2,000,000 \text{ J}}$. Initial PE = 0.

Let d = distance travelled along the ramp. Height gained $= d/2$.

Final PE $= mg \times (d/2) = 10000 \times 10 \times (d/2) = 50,000 \text{ N} \times d$. Final KE = 0.

Work done by sand on truck $= -50,000 \text{ N} \times d = \text{change in total energy} = (50,000 \text{ N} \times d) - 2,000,000 \text{ J}$

$2,000,000 \text{ J} = 100,000 \text{ N} \times d \Rightarrow d = \mathbf{20 \text{ m}}$

The escape ramp must be at least 20 m long to safely stop this truck.

▣ Thread of Curiosity: Why Nothing Runs Forever

Could a wheel, once spun, keep turning forever and power a city — a true **perpetual motion machine**? History is full of failed attempts, and interestingly, one of the earliest recorded design ideas comes from India: the 12th-century mathematician-astronomer **Bhaskaracharya (Bhaskara II)** described, in his treatise the *Siddhanta Shiromani*, a wheel with curved, mercury-filled spokes that he suggested would keep spinning under its own shifting weight. No version of this — or any perpetual motion machine proposed since — has ever actually worked, because every real machine loses a little energy to friction and air resistance at every turn. The conservation of energy tells us why: **energy can change form, but a closed system can never manufacture more of it from nothing.**

7.5 Power

Carrying your schoolbag up a flight of stairs feels very different when you sprint up in 20 seconds versus climbing slowly over 2 minutes — yet the **work done** (against gravity, over the same height) is identical in both cases. What's different is **how fast** that work is done, and physics calls this rate **power**.

Definition

power = work done ÷ time taken

$$P = W / t \quad (\text{Eq. 7.11})$$

The SI unit of power is the **watt (W)**: $1 \text{ W} = 1 \text{ J s}^{-1}$. Doing more work in the same time, or the same work in less time, both require more power.

Meet a Scientist: James Watt (1736-1819)

The watt is named after Scottish engineer **James Watt**, whose improvements to the steam engine in the 18th century made it dramatically more efficient, powering the machines of the Industrial Revolution. In the early days of engines, their output power was compared to that of actual horses used to pull carriages and mill-wheels — which is where the still-used unit **horsepower (hp)** comes from. $1 \text{ hp} = 746 \text{ W}$, and you'll still see it quoted for car and motorbike engines and water pumps today.

□ Everyday Connection: The '1 HP Motor' on Your Terrace

Walk up to the water pump on many Indian apartment terraces and you'll see a nameplate reading '1 HP' or '0.5 HP' — that's literally the motor's power rating in horsepower, still in everyday use nearly two and a half centuries after Watt. A more powerful pump moves the same tankful of water to the rooftop tank in less time, exactly as Eq. 7.11 predicts. E-bikes and e-scooters sold in India today are commonly rated in watts instead — 250 W, 1000 W, 3000 W — the same physical quantity, just a different (and now more common) unit.

□ Worked Example 7.8 — Redeveloped: A Weightlifter's Power Output

Original book version: A weightlifter lifts 75 kg by 2 m in 5 seconds — find the power required.

Everyday Version (kept as-is — already grounded):

$$\text{Work done} = mgh = 75 \text{ kg} \times 10 \text{ m s}^{-2} \times 2 \text{ m} = 1500 \text{ J}$$

$$\text{Power} = 1500 \text{ J} / 5 \text{ s} = \mathbf{300 \text{ W}}$$

□ Worked Example 7.9 — Redeveloped: Accelerating an E-Scooter

Original book version: A 1000 kg car accelerates from rest to 72 km h^{-1} in 10 seconds — find the engine's power.

Everyday Version: Swap the car for a compact electric hatchback used for last-mile deliveries, total mass 1000 kg, accelerating from rest to $72 \text{ km h}^{-1} = 20 \text{ m s}^{-1}$ in 10 s.

$$\text{Work done by motor} = \text{final KE} - \text{initial KE} = \frac{1}{2} \times 1000 \text{ kg} \times (20 \text{ m s}^{-1})^2 - 0 = \mathbf{200,000 \text{ J}}$$

$$\text{Power} = 200,000 \text{ J} / 10 \text{ s} = \mathbf{20,000 \text{ W}} = 20 \text{ kW} (\approx 27 \text{ hp})$$

7.6 Simple Machines

We often need to do work against gravity or other forces — lifting sacks, drawing water, moving furniture. The **total work required for a task cannot be reduced** by any device. But it *can* be made to feel easier by changing the **magnitude or direction** of the force we must apply. Devices that do this are called **simple machines**.

The force we apply to a machine is the **effort**; the force we need to overcome is the **load**. We define:

Definition

mechanical advantage = load ÷ effort

mechanical advantage = load / effort (Eq. 7.12)

We'll study three simple machines — the pulley, the inclined plane, and the lever.

7.6.1 Pulley

A pulley is a grooved wheel that guides a rope. A **fixed pulley** doesn't reduce the force required — it only **changes its direction**, making it easier to pull downward than to lift a load by applying force directly upward. Since effort equals load in magnitude, a fixed pulley's mechanical advantage is exactly **1**.

□ Everyday Connection: The Village Well Pulley (and the Gym Cable Machine)

In many Indian villages, wells still use exactly this arrangement — a wheel fixed at the top with a rope running over it, so hauling up a bucket of water means pulling **down** on the rope instead of lifting straight up. It's often mechanically no easier (mechanical advantage 1!), but pulling downward lets you use your body weight and stand comfortably at ground level rather than reaching over the well's edge — convenience, not force reduction.

A modern gym's lat-pulldown or cable-row machine works on the very same principle, just with more pulleys and adjustable weight stacks — many gym machines actually use **movable pulley systems** (mechanical advantage greater than 1) to let you lift more effective weight with less applied force, which is exactly what the box below explores.

□ Ready to Go Beyond: Movable Pulleys and Cranes

A **movable pulley** — where the load hangs from the pulley itself rather than from a fixed point — can give a mechanical advantage greater than 1, letting a much smaller effort lift a much heavier load, at the cost of pulling the rope through a longer distance. Elevators, tower cranes on Indian construction sites, and window-cleaning cradles on skyscrapers all rely on systems of multiple movable and fixed pulleys working together.

7.6.2 Inclined plane

Lifting a heavy box straight up onto a platform needs an upward force equal to its full weight. Pushing the same box up a smooth ramp instead needs **less force** — but over a **longer distance**.

□ Activity 7.3 — Redeveloped: Rolling a Delivery Trolley Up a Ramp

Original book version: Pull a toy cart up an inclined cardboard plank using a spring balance, and compare the force needed at different ramp angles.

Everyday Version: Picture a delivery worker loading parcels onto a truck using a portable aluminium ramp instead of lifting boxes straight up into the truck bed — exactly the kind of ramp you'll see outside courier depots and even at metro stations helping wheelchair users board. Using a toy cart, a spring balance, and a cardboard ramp against a stool of fixed height, measure the force needed to (a) lift the cart straight up, and (b) pull it up the ramp. Then

make the ramp less steep (longer, shallower) and measure again.

You'll find the force needed **decreases** as the ramp gets less steep — but you have to pull the cart over a correspondingly **larger distance** to reach the same height. The work done stays the same throughout.

Let m be the object's mass (so mg is the load), F' the effort needed to push it up a smooth incline of length L to height h . Moving at constant speed (ignoring friction), the work-energy theorem gives us:

total work done = $F' \times L$ = potential energy gained = mgh , so $mg/F' = L/h$

Definition

mechanical advantage of an inclined plane = load / effort = $mg/F' = L/h$
(Eq. 7.13)

Since $L > h$, the mechanical advantage is always greater than 1 — and making the ramp longer and shallower increases it further.

□ Everyday Connection: Why Ghat Roads Zigzag

Highways climbing into the Himalayan foothills or the Western Ghats almost never go straight up a hillside — they wind back and forth in long, gentle hairpin bends. A longer, shallower road (a very long, shallow inclined plane) requires far less force — and less strain on vehicle engines and brakes — to gain the same altitude than a short, steep one would, exactly as Eq. 7.13 predicts. It's the same reason a wheelchair ramp is always built long and gradual rather than short and steep.

□ Worked Example 7.10 — Redeveloped: A Metro-Station Access Ramp

Original book version: A person uses an inclined ramp to raise an object over a 30 cm step; the ramp is 40 cm wide (i.e., its horizontal base is 40 cm) — find its mechanical advantage.

Everyday Version (kept close to original — numbers preserved exactly): A wheelchair-accessible ramp outside a metro station rises 30 cm over a horizontal base of 40 cm. What is its mechanical advantage?

By the right-angled triangle property: $L^2 = 30^2 + 40^2 = 900 + 1600 = 2500$, so $L = 50$ cm

mechanical advantage = $L/h = 50 \text{ cm} / 30 \text{ cm} = \mathbf{1.67}$

7.6.3 Lever

A **lever** is a rigid bar that rotates about a fixed point called the **fulcrum**. Its three parts: the **fulcrum**, the **load** (force to overcome), and the **effort** (force applied). The distance of the load from the fulcrum is the **load arm**; the distance of the effort from the fulcrum is the **effort arm**.

□ Activity 7.4 — Redeveloped: Lifting a Stapler with an Eraser

Original book version: Balance a 30 cm scale over a pencil, placing a stapler near one end and erasers near the other, to lift the stapler with much less force.

Everyday Version: Take a 30 cm ruler, a pencil, a phone charger (as the 'heavy load'), and a couple of erasers (as the 'light effort'). Rest the ruler across the pencil close to one end, with the charger on the short end. Add erasers to the long end until it just lifts the charger. You'll find a **small effort at the far end lifts a much heavier load** near the fulcrum.

If a small force F_1 applied at one end moves through a large distance d_1 , while a larger force F_2 is applied to a load at the other end through a smaller distance d_2 , then since work transferred through the lever must balance (Eq. 7.1):

$$F_1 \times d_1 = F_2 \times d_2 \quad (\text{Eq. 7.14})$$

Activity 7.5 — Redeveloped: The Sabzi-Wali's Tarazu

Original book version: Hang a scale from a string at its midpoint, with paper cups tied at each end as pans, and use coins as weights to explore how a beam balance balances.

Everyday Version: Recall the vendor's **tarazu** (balance scale) from your local sabzi mandi — it's a lever in its purest form. Build one: hang a long ruler by a string at its centre (the fulcrum), and tie a paper cup to each end as pans. Place 1 coin in each pan — it balances. Now put 2 coins on one side; the beam tips. Slide that heavier pan closer to the centre until it balances again, and record the distance from the centre. Repeat with 4 and then 8 coins.

You'll find the beam balances whenever: $n_1 \times L_1 = n_2 \times L_2$ — that is, effort $\times$ effort arm = load $\times$ load arm (Eq. 7.15)

Definition

mechanical advantage of a lever = load / effort = effort arm / load arm (Eq. 7.16)

Increasing the effort arm relative to the load arm lets a lever multiply a small applied force into a much larger one at the load — though as always, the effort must move a correspondingly larger distance, so total work done stays the same.

Worked Example 7.11 — Redeveloped: Balancing a Park Seesaw

Original book version: On a seesaw with seats A, B, D, E and fulcrum C (AC = EC = 2 m, BC = DC = 1 m), where should a 15 kg child and a 30 kg child sit to balance?

Everyday Version (kept as-is — already a familiar park scenario):

The 15 kg child sits at A (2 m from fulcrum C). Let the 30 kg child sit at distance L .

$15 \text{ kg} \times 2 \text{ m} = 30 \text{ kg} \times L \Rightarrow L = 1 \text{ m}$ — so the 30 kg child should sit at **seat D**.

Levers fall into three classes, based on the relative positions of effort, fulcrum, and load:

Class	Arrangement	Everyday Indian examples
Class I	Fulcrum in between load and effort	Scissors, pliers, tongs, a crowbar, a seesaw, a beam balance (tarazu)
Class II	Load in between fulcrum and	A wheelbarrow (thela), a bottle

Class	Arrangement	Everyday Indian examples
	effort	opener, a nutcracker/sarauta (used to cut areca nut)
Class III	Effort in between fulcrum and load	Tweezers, a broom, a fishing rod, an oar, a cricket bat swing

□ Everyday Connection: Prying Open a Paint Tin with a Spoon

Ever noticed how much easier it is to lift a stuck lid using the long handle of a spoon as a lever, rather than your fingers alone? You're increasing your effort arm relative to the load arm, gaining mechanical advantage exactly as Eq. 7.16 describes. The same idea explains why you push a heavy object closer to a pair of scissors' fulcrum (a shorter load arm) when it's hard to cut — that increases the *ratio* of effort arm to load arm at that point, multiplying the cutting force.

Meet a Scientist: Sir M. Visvesvaraya (1861-1962)

One of India's most celebrated engineers, **Sir Mokshagundam Visvesvaraya**, designed automatic floodgates for the Krishna Raja Sagara (KRS) dam in Karnataka and pioneered systems of flood-protection and irrigation across the country — engineering built on exactly the mechanical principles in this chapter, applied at enormous scale. His birthday, 15 September, is celebrated in India as **Engineer's Day**, honouring his legacy of turning physics into public infrastructure.

Bridging Science and Society: The Himalayan Gharat

In the hill regions of Uttarakhand and Himachal Pradesh, traditional water mills called **gharat** or **panchakki** still grind grain using nothing but gravity. Water starts at the top of a channel with potential energy; as it rushes down a pipe, that potential energy converts to kinetic energy, which spins a wheel connected by a shaft to a grinding stone above. Modern hydroelectric dams use exactly the same conversion — from stored gravitational potential energy in a reservoir, to kinetic energy of falling water, to electricity — just at a far larger scale.

Most machines you encounter — from a bicycle to a construction crane — are combinations of these simple machines working together. Machines never create energy; they only help us apply it more conveniently, redirecting force at the cost of distance, never violating the conservation of mechanical energy.

Chapter Summary

Concept	Core idea	Everyday example
Work	$W = F \times s$; work done only along the direction of the force	Lifting an atta sack; pushing a stuck wall does zero work
Work-energy theorem	Work done on an object = change in its energy	A bowled cricket ball gains energy from the bowler's throw

Concept	Core idea	Everyday example
Forms of energy	Mechanical, thermal, light, sound, electrical, nuclear, chemical	Charging a phone: chemical $\rightarrow$ electrical $\rightarrow$ light/sound
Kinetic energy	$K = \frac{1}{2}mv^2$; quadruples if speed doubles	A two-wheeler's crash energy quadruples if speed doubles
Potential energy	$U = mgh$; also stored in stretched/compressed objects	A gulel's stretched band; a coconut poised to fall
Conservation of mechanical energy	$KE + PE$ stays constant without friction	A park jhula swinging back to nearly its starting height
Power	$P = W/t$; SI unit watt (1 hp = 746 W)	A rooftop water pump rated '1 HP'; an e-scooter's motor in watts
Simple machines	Mechanical advantage = load/effort; change force, not total work	A well pulley, a ghat road ramp, a sabzi-wali's tarazu

□ Revise, Reflect, Refine — Exercises

Basic Recall

1. A friend says, 'I pushed our stalled scooter for ten minutes and did no work at all, because it never moved.' Using the scientific definition of work, explain whether this statement is correct, and why the friend still felt exhausted.
2. State the work-energy theorem in your own words, and name the SI unit shared by work, kinetic energy, and potential energy.
3. Define mechanical advantage. For a fixed pulley used to raise a flag, what is its mechanical advantage, and why?

Apply & Think

4. **(Numeric)** An electric scooter, together with its rider, has a total mass of 100 kg. It accelerates from rest to 36 km h^{-1} in 5 seconds on a flat road. Calculate (i) its final kinetic energy, and (ii) the average power delivered by the motor during this acceleration.
5. A mason uses a movable-pulley system with a mechanical advantage of 2 to lift a 40 kg bag of cement. Taking $g = 10 \text{ m s}^{-2}$, what effort must the mason apply? If the same bag were lifted using a fixed pulley instead, how would the required effort change — and what would change about the direction in which the mason pulls?
6. A social media post claims a newly invented 'free energy wheel' can spin forever and continuously power a home with no fuel input at all. Using the ideas of work, energy, and conservation of mechanical energy from this chapter, explain what is scientifically wrong with this claim.

Creative Design Challenges □

7. **The Pen-Rocket Launcher:** Remove both ends of an old pen so the refill slides freely through the barrel. Fix the pen cap to the barrel's side and attach a rubber band to its clip; connect the rubber band's free end to the refill with a safety pin. Stretch and release the band to launch the refill, converting elastic potential energy into kinetic energy. Test at least three different amounts of stretch and record the distance travelled each time. Is there a clear relationship between stretch and distance? Present your data as a simple table or graph.

8. **Design a Ramp for Your Building:** Your school or housing society wants to make an entrance more wheelchair-accessible by replacing a set of 3 steps (each 15 cm high) with a ramp. Decide on a ramp length that keeps the mechanical advantage reasonably high, calculate the mechanical advantage of your design, and explain your reasoning.

9. **Invent a Machine for a Real Problem:** Think of a genuine everyday task in Indian homes or farms that is still physically hard (for example: lifting water from a low tank, helping an elderly relative climb stairs, or hauling produce from a field to a cart). Design a simple machine or combination of machines (lever, pulley, inclined plane) to make it easier. Sketch your idea, identify the effort and the load, and estimate its mechanical advantage.

10. **AI Creative Spark — The Energy Audit:** Using a fitness-tracker app or a rough estimate, calculate the approximate work you do (in joules) climbing the stairs to your classroom or apartment once. Then estimate how many times you'd need to repeat this climb to 'burn' the energy in one samosa ($\sim 250 \text{ kcal} \approx 1,046,000 \text{ J}$). Show your assumptions and working clearly.

□ Journey Beyond — Going Deeper

Challenge A: Build Your Own Simple Machine

Using easily available materials — cardboard, wooden rulers, pencils or bolts (as a fulcrum), thread, small pulleys or two bottle caps stuck together, and paper cups for weights — construct a lever, a pulley system, an inclined plane, or a combination of them. Use your model to lift or move a small load, measure the effort and the load with a spring balance or improvised weights, and calculate its actual mechanical advantage. Then compare this to what the theoretical formula (Eq. 7.13 or 7.16) predicts. If they don't match exactly, what real-world factor (hint: something we've been asked to 'neglect' throughout this chapter) do you think explains the gap?

Challenge B: Simulate It

Explore interactive simulations such as PhET's *Energy Skate Park*, *Pendulum Lab*, or *Masses and Springs* (available free at phet.colorado.edu). Vary parameters like mass, height, and friction, and observe how kinetic and potential energy trade off in real time. Write a short note (150–200 words) describing one surprising observation from your exploration and connecting it to the conservation of mechanical energy.

Challenge C: The Mystery of Dark Energy

Scientists have long known the universe is expanding — and, remarkably, that this expansion is *accelerating*. To explain this, physicists have proposed a mysterious form of energy called **dark energy**, which cannot (as far as we know) be exchanged with any other form of energy we've studied in this chapter. Research what dark energy is currently believed to be, and write a short reflection: does its existence challenge the

conservation of mechanical energy you learned in section 7.4.3, or does it operate on a scale and a set of rules entirely outside it? What questions would you want answered if you became a cosmologist studying this problem?

Happy Exploring! Every lever you pull, every ramp you climb, and every pulley you spin is physics quietly doing work for you.